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# Chromospheric activity on the RS Canum Venaticorum stars

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**ABSTRACT**
Firstly, we review the stellar chromospheric activity in the optical wavelength. Secondly, we introduce our ongoing project of multi-wavelength high–resolution optical observations aimed at studying the chromospheric activity of different RS CVn stars. Finally, we give our future perspectives.

**Key words:** Star: RS CVn, Star: Chromosphere, Activity: plage, Activity: flare

## 1 INTRODUCTION

This is a brief review of stellar chromospheric activity. In this section, we will discuss the definition of chromosphere, chromospheric activity, chromospheric activity indicators and diagnostic technique.

### 1.1 What is a chromosphere

In classical, the chromosphere is an intermediate region in the atmosphere of a star, lying above the photosphere and below the corona. At present, Hall (2008) gave us a working definition of the chromosphere. It is the region of a stellar atmosphere where we observe emission in excess of that expected in radiative equilibrium and where cooling occurs mainly due to radiation in strong resonance lines (rather than in the continuum, mostly the case in the photosphere) of abundant species such as Mg II and Ca II.

### 1.2 Chromospheric activity

For late-type stars with thick convective zones and rapid rotation, they exhibit chromospheric activity phenomena such as plage and flare, which are tightly linked to changes of the stellar magnetic field. Chromospheric plage produces emission in the cores of the Ca II H&K lines (Fig.1). For the observations of HR 1099 obtained by García-Alvarez et al (2003), optical flare was detected (see Fig. 2). The equivalent widths (EWs) of $H_\alpha$ emission increase by almost a factor of 4.

By analyzing the chromospheric activity variation with orbital phase, astronomers have found some stars show rotational modulation phenomena. Fig.3 shows a example of a clear rotational modulation of the $H_\alpha$ emission of LQ Hya (Frasca et al. 2008). They applied a simple geometric plage model to explain the rotational modulated chromospheric emission. The most prominent monitoring programme of solar-type chromospheric activity is called the HK project (Wilson 1963, 1978). Long term monitoring of chromospheric activity has revealed that many cool stars show different activity cycles (see Fig.4) (Berdyugina 2005).

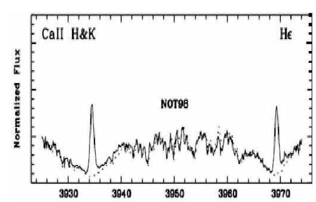


**Figure 1.** The Ca II H&K profiles of $\sigma$ Gem (Montes et al. 2000).

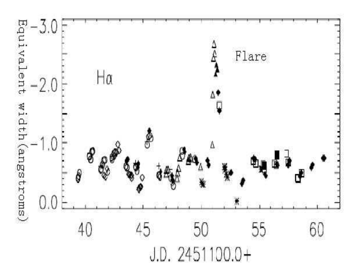


**Figure 2.** The $H_\alpha$ equivalent width as a function of Julian date for HR 1099 (García-Alvarez et al. 2003).

### 1.3 Chromospheric activity indicators

Chromospheric activity produce fill-in or emission in some strong photospheric lines. Usually we use these lines as chromospheric activity indicators. These indicators are summarized as follows:

**The Na I $D_1$, $D_2$ lines and Mg I b triplet lines:**

The Na I $D_1$, $D_2$ and Mg II b triplet lines are formed in the upper photosphere and lower chromosphere. Both Na I and Mg I lines are detected during flares as emission reversal or as filled-in absorption (Andretta et al. 1997; Montes et al. 1997; Montes et al. 2004).

**The Ca II infrared triplet (IRT) lines:**

The Ca II IRT lines are important chromospheric activity indicators for the Sun and late-type stars (Gunn &

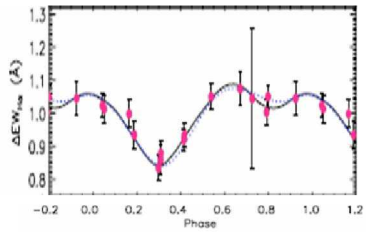


**Figure 3.** Rotational modulation of the residual $H_\alpha$ equivalent width of LQ Hya. The solid line represents the best fit of 3-plage model, while the dotted line represents 2-plage model (Frasca et al. 2008)

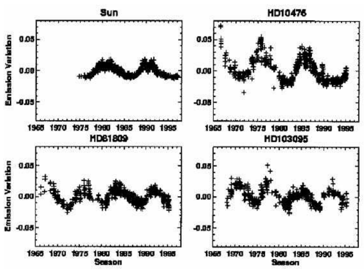


**Figure 4.** Chromospheric Ca II emission cycles for Solar-like stars, illustrating the regular, cyclic variation that is common in such stars. The Ca II emission is plotted in Mount Wilson S-Index units (Radick 2000).

Doyle 1997; Montes et al. 1997; Montes et al. 2000). They are formed in the lower chromosphere, making them sensitive probes of the temperature minimum region (Montes et al. 1997). The ratio of excess emission, $EW_{8542}/EW_{8498}$, is an indicator of the chromospheric structure (plages, prominences). In solar plages, the values of $EW_{8542}/EW_{8498}$ are in the range 1.5-3 (Chester 1991). These low values are also found in other chromospherically active binaries by other authors: Lázaro & Arévalo (1997); Montes et al. (2000) and Gu et al. (2002). While in solar prominences, the values are about 9 (Chester 1991).

**The $H_\alpha$, $H_\beta$ and other Balmer lines:**

The Balmer lines are very useful indicators of chromospheric activity and formed in the middle chromosphere (Montes et al. 1997, etc.). For less active stars, these line profiles are filled-in absorption. While for much active stars, they are emission above the continuum. The ratio $EW_{H_\alpha}/EW_{H_\beta}$ can be used as a diagnostic indicator for discriminating between plages and prominences (Hall & Ramsey 1992; Montes et al., 2004). According to Buzasi model, the low ratio (1-2) can be achieved both in plages and prominences viewed against the disk, but the high ratio ($> 3$, to a theoretical maximum of about 15) can only be achieved in extended regions viewed off the limb (Hall & Ramsey 1992).

**The Ca II H&K lines:**

The Ca II H&K lines have been the traditional diagnostic indicators of chromospheric activity in cool stars for long time. They are formed in the middle chromosphere. The emissions in the cores of these lines are the most widely used optical indicators of chromospheric activity.

**The He I $D_3$ lines:**

The He I $D_3$ line is formed in the upper chromosphere. The emission of the line is a probe for detecting flare-like events (Zirin 1988).

**1.4 Diagnostic technique**

To extract the chromospheric contribution from the spectra line, the method is the spectral subtraction technique. The principle of the method is that chromospheric contribution equals to observed spectra minus the synthesized spectra. The problem of the technique is to simulate the correct synthesized spectrum representing the underlying photospheric contribution. There are two approaches. One is using theoretical spectra based on radiative transfer solutions of model atmospheres (Fraquelli 1984). The theoretical line profiles were calculated from the model atmospheres by using the known effective temperature and surface gravities of the active system. The problem with theoretical line profiles for spectral subtraction is the uncertainty and complexity of the atmospheric conditions. Without detailed information concerning the dominating effects on the source functions of active lines and the effects of active regions on these lines, it is impossible to form adequate theoretical representation of the inactive contribution (Gunn & Doyle 1997). The other is using observed spectra of inactive stars. The synthesized spectrum is constructed from artificially rotationally broadened, radial-velocity shifted, and weighted spectra of inactive stars with the same spectral type and luminosity class as the components of the active system (Barden 1985). There are some assumptions in this spectral subtraction technique (Barden 1985; Gunn & Doyle 1997). Usually we use the second method.

## 2 OUR ONGOING PROJECT

We aim to study the chromospheric activity of different RS CVn stars. By analyzing the simultaneous spectroscopic observations of several chromospheric activity indicators for the RS CVn binary systems, and by using the spectral subtraction technique, we have investigated the detail of the excess emission and studied the chromospheric activity variation with orbital phase and different epoches.

The main observational method is high-resolution spectroscopy. The telescope and instrumental configuration is 2.16 meter telescope with echelle spectrograph of Xinglong station, NAOC. The used wavelength region is from 5600 to 9000 $\mathring{A}$ and the resolution is about 37,000. Up to now, we have analyzed chromospheric activity on the RS CVn binary SZ Psc ($P_{rot}$=$3^d.97$, F8V+K1IV) (Zhang & Gu 2008). Our spectroscopic observations were made in four observing runs: Sept. 1-6, Oct. 28-29, Nov. 28-30, and Dec. 8-10, 2006. Each observational run includes the optical chromospheric indicators: the He I $D_3$, Na I $D_1$, $D_2$, $H_\alpha$, and Ca II IRT lines. The method we used is the spectral subtraction technique and the code is starmod developed by Barden (Barden 1985). Some examples of the different chromospheric indicators are displayed in Fig.5.

The application of the spectral subtraction technique reveals that the Na I $D_1$, $D_2$ lines, in some cases, exhibit obvious excess emission from the cooler component. For the He I $D_3$ line, there is no obvious absorption or emission. So, during our observing seasons, we observed no flare-like episodes. For the Ca II IRT lines, they show obvious excess emission from the cooler component. For the $H_\alpha$ line,

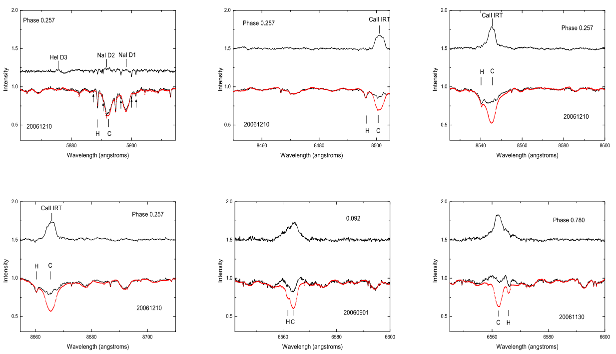

**Figure 5.** Samples of the observed, synthesized, and subtracted spectra for the He I $D_3$, Na I $D_1$, $D_2$, Ca II IRT and $H_\alpha$ lines. The dotted lines represent the synthesized spectra and the upper spectra are the subtracted spectra. Vertical arrows mark the telluric lines that appeared in the spectral region.

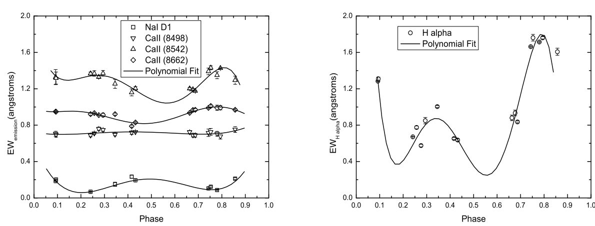


**Figure 6.** The EWs of the excess emissions vs. orbital phase for Na I D, Ca II IRT and $H_\alpha$ lines. The solid line refers to a polynomial fit to the data.

it shows excess emission from the cooler component and the excess emission profiles exhibit broad wings. There are a couple of possible explanations for the $H_\alpha$ line. First, the broad component could be interpreted as arising from microflaring. Second, it might be caused by instantaneous mass transfer from the cooler component to the hotter one(Bopp 1981). In summary, all these analyzed activity indicators show that the cooler component is active.

We measured the EWs of the excess emissions. To discuss the rotational modulation of chromospheric activity, we used all these data because we only have 3 to 4 data points per rotation in different epochs. Fig.6 shows the EWs with orbital phase. We used polynomial function to fit the data. For the Ca II 8498 data, there is no significant trend. While for the Ca II 8542 and 8662 lines, especially for the Ca II 8542 line, it seems that the emission is stronger near phases 0.25 and 0.75. For the $H_\alpha$ line, it seems that the emissions is stronger near phase 0.3 and 0.75. Therefore, for the CaII 8542 and 8662 and $H_\alpha$ lines, the excess emissions (with the orbital phase) may be correlated basically, especially around two quadratures. The emissions are stronger around two quadratures of the system (phases 0.25 and 0.75). However, for the Na I $D_1$ line, the emission is weaker around the two quadratures, so the Na I $D_1$ line may be anti-correlated with the Ca II 8542, 8662 and the $H_\alpha$ lines.

## 3 PERSPECTIVE

We would like to give our future plan, as follows:
1. Monitor long-term chromospheric activity of SZ Psc.
2. Chromospheric activity studies of other RS CVn stars.
3. UV, x-ray and radio studies of selected RS CVn objects.

Finally, we will investigate the chromospheric activity evolution with age and its dependency on stellar parameters such as stellar rotation, mass and so on.

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